Development of Augmented Spark Impinging Igniter System for Methane Engines

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Overview

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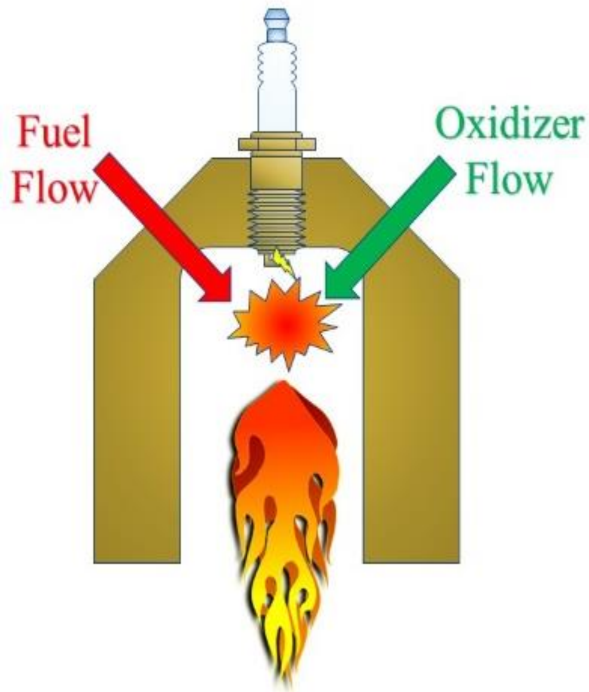
Introduction

- The Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) program is establishing multiple no-funds-exchanged Space Act Agreement (SAA) partnerships with U.S. private sector entities
  - The purpose of this program is to encourage the development of robotic lunar landers that can be integrated with U.S. commercial launch capabilities to deliver payloads to the lunar surface.
  - NASA can share technology and expertise under the SAA for the benefit of the CATALYST partners
- MSFC seeking to vacuum test in-house designed Augmented Spark Impinging (ASI) igniter with methane and new exciter units to support CATALYST partners and NASA programs
  - ASI has previously been used/tested successfully at sea-level, with both O_2/CH_4 and O_2/H_2 propellants

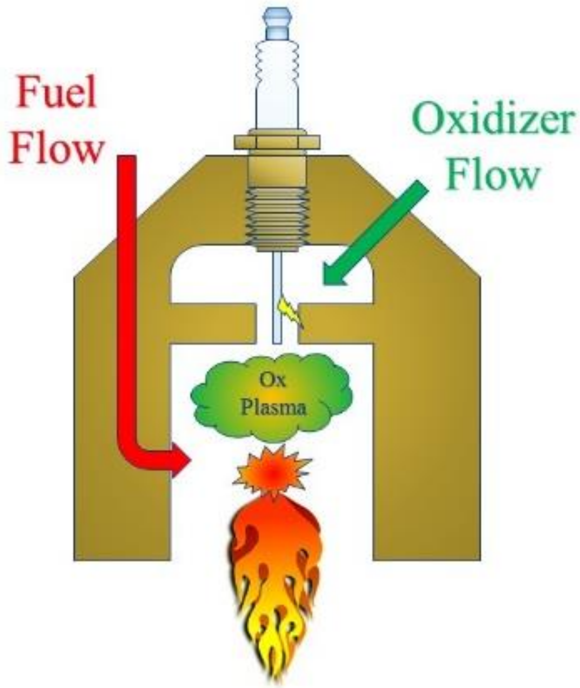
Brief History of Methane Spark Ignition Work at NASA

- NASA interested in further developing methane engine technology
  - Methane has several advantages as propellant choice
  - Numerous efforts in 2000's sought risk reduction goals
    - Many test programs conducted as part of PCAD program
    - Methane ignition was seen as one particular focus for risk reduction
- Several test programs investigated LOX/LCH_4 spark ignition specifically for methane risk reduction efforts
  - Igniters were both in-house and commercially developed
  - Investigated various parameters, such as propellant temperatures, impact of hardware temperatures, reliability, mixture ratio, vacuum ignition, etc.
  - A 100-lbf (445-N) RCE with integrated igniter was also used to examine minimum spark energy and timing relative to flows
- Two primary styles of spark igniters examined
  - "Single Chamber" uses direct spark ignition of combustible mixture
  - "Plasma-Assisted" uses spark to energize oxygen plasma (up to 100% of ox flow), plasma ignites combustible mixture

Brief History of Methane Spark Ignition Work at NASA



Single Chamber



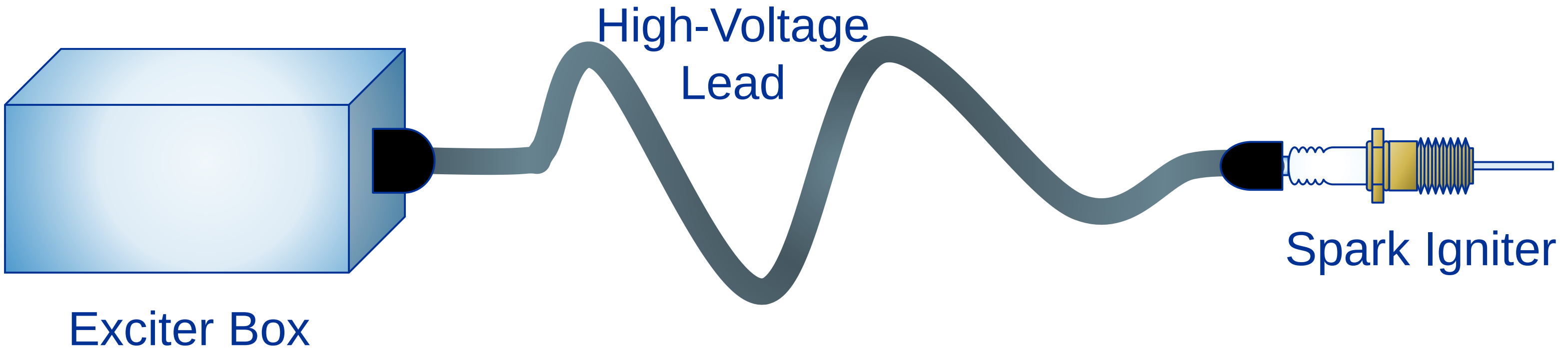
Plasma-Assisted

Brief History of Methane Spark Ignition Work at NASA

Igniter Program	Igniter Developer	Reference Paper	Igniter Type
870-lb_f LOX/LCH_4 RCE	Commercial	Hurlbert, et al. (AIAA 2008-5247) Robinson, et al. (AIAA 2005-4457)	Plasma-Assisted
GRC Workhorse Igniter	NASA GRC	Schneider, et al. (NASA TM 2007-215038)	Plasma-Assisted
LOX/Methane Main Engine Igniter	NASA GRC	Breisacher and Ajmani (AIAA-2008-4757)	Single Chamber
100-lb_f LOX/LCH_4 RCE	Commercial	Kleinhenz, et al. (NASA TM 2012-217611) Marshall, et al. (NASA TM 2012-217613)	Plasma-Assisted
PCAD Ignition Risk Reduction	Various (GRC/MSFC/ Commercial)	Smith, et al. (AIAA 2010-8680) Brown, et al. (Space Propulsion 2016) Robinson (Space Propulsion 2010)	Single Chamber and Plasma-Assisted
Project Morpheus RCS/ ICPTA	NASA JSC	Hurlbert, et al. (AIAA 2011-6113) McManamen, et al. (AIAA 2014-3589) Hurlbert, et al. (AIAA 2016-4681) Melcher et al. (to be published AIAA 2017)	Plasma-Assisted (Coil-on-Plug exciter)

Spark Exciter Systems

- Conventional ignition exciter systems historically experienced corona discharge issues in altitude (low-pressure) environments
  - Often utilized purging or atmospheric sealing on high voltage lead to remedy
- "Compact" systems developed since PCAD could eliminate the high-voltage lead and directly couple the exciter to the spark igniter



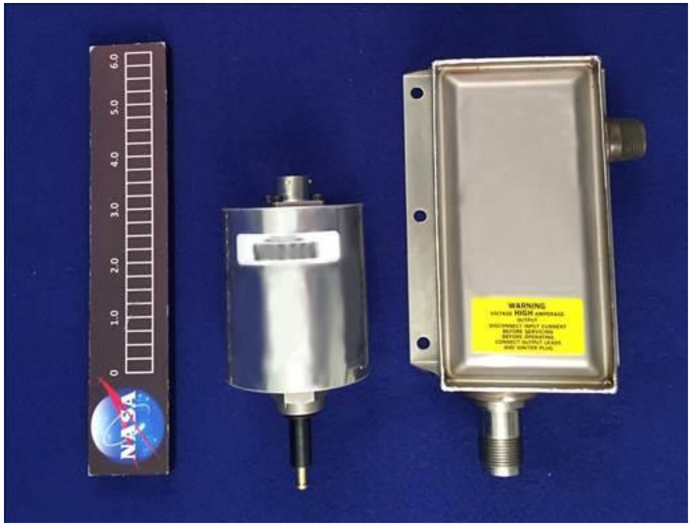
Cartoon of a typical conventional ignition exciter system

Overview of MSFC ASI Igniters and Exciters

- MSFC developed Augmented Spark Impinging (ASI) igniter
- Successfully used in several sea-level test programs
- Plasma-assisted design
  - Portion of ox flow is used to generate hot plasma
- Impinging flows downstream of plasma
- Additional fuel flow down torch tube sleeve for cooling & near stoichiometric torch flame

Overview of MSFC ASI Igniters and Exciters

- Champion Aerospace designed spark igniter (spark plug)
- An annular gap is formed between the spark igniter electrode and the ASI igniter body
- Two styles of Exciter tested
  - Compact-Style Exciter
    - 200 sparks per second (SPS) @ ~8 mJ delivered* spark energy
    - Eliminates high voltage lead
  - Conventional-Style Exciter
    - 83 SPS @ ~50 mJ delivered* spark energy
    - Improved sealing around high voltage lead



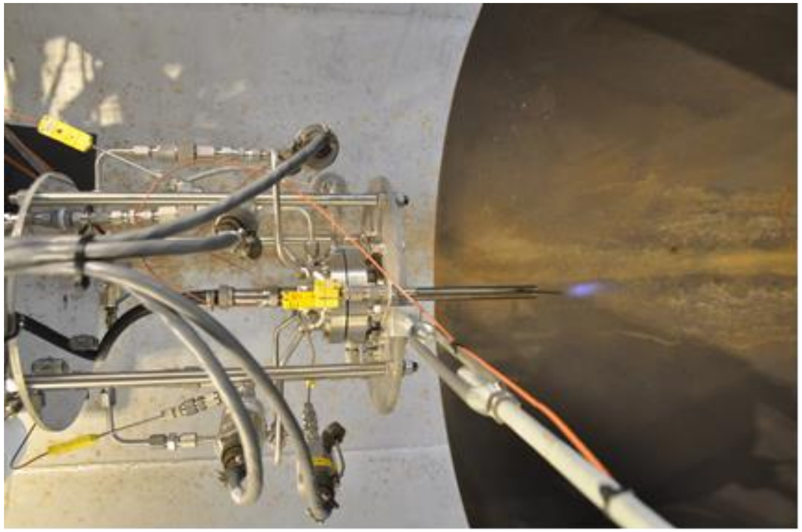
* MSFC estimated values based upon measurements of voltage and current in an instrumented ignition lead while sparking in quiescent air. Values are specific to the spark gap geometry used in the ASI igniter.

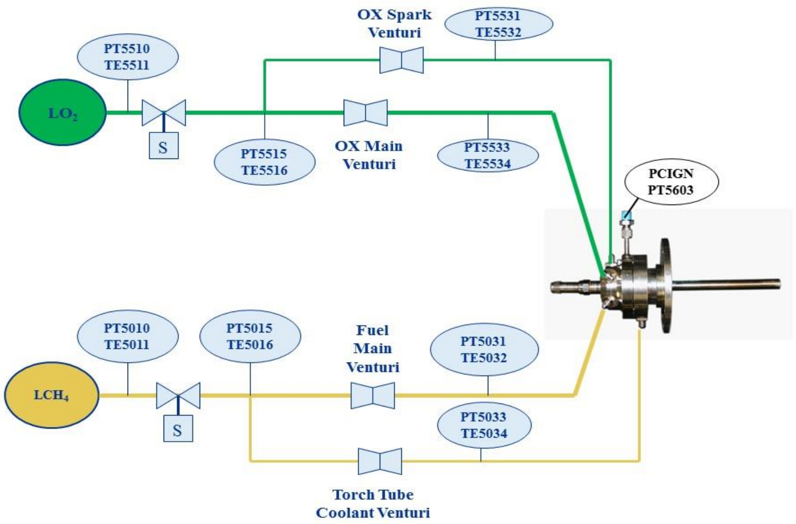
Test Facility and Setup

- Testing done at NASA GRC Altitude Combustion Stand (ACS) facility
- 2000-lbf class facility with altitude simulation up to around 100,000 ft. (~0.2 psia [10 Torr]) via nitrogen driven ejectors
- Propellant conditioning systems can provide temperature control of LOX/LCH_4 up to test article

Test Facility and Setup

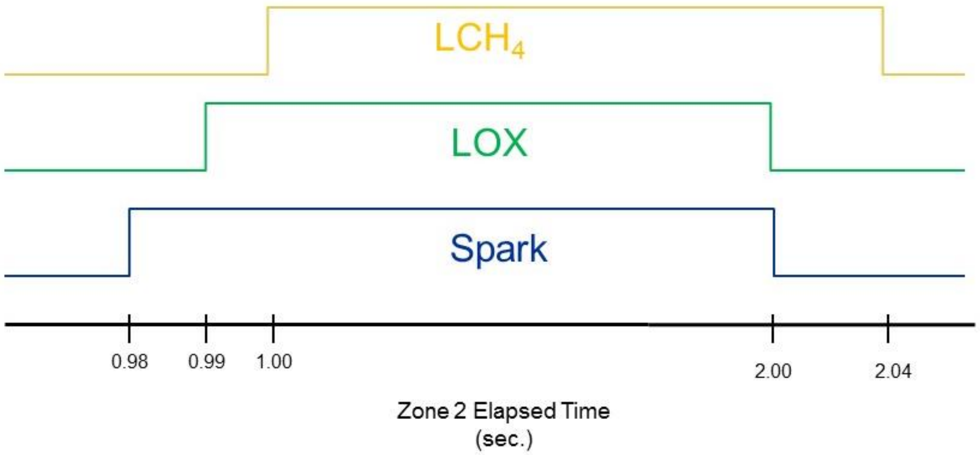
- Most tests conducted at altitude conditions (~0.5 psia [25 Torr])
- Setup utilized prior PCAD facility integration with liquid propellants, but no line cooling downstream of thruster valves
  - Propellants assumed to vaporize by the time they reach igniter
- “Sonic” venturi used to regulate mass flows
- Flowrates and O/F to match those of prior MSFC experience (O/F_{core} ~ 40; $O/F_{overall}$ ~ 5)





Results and Discussion

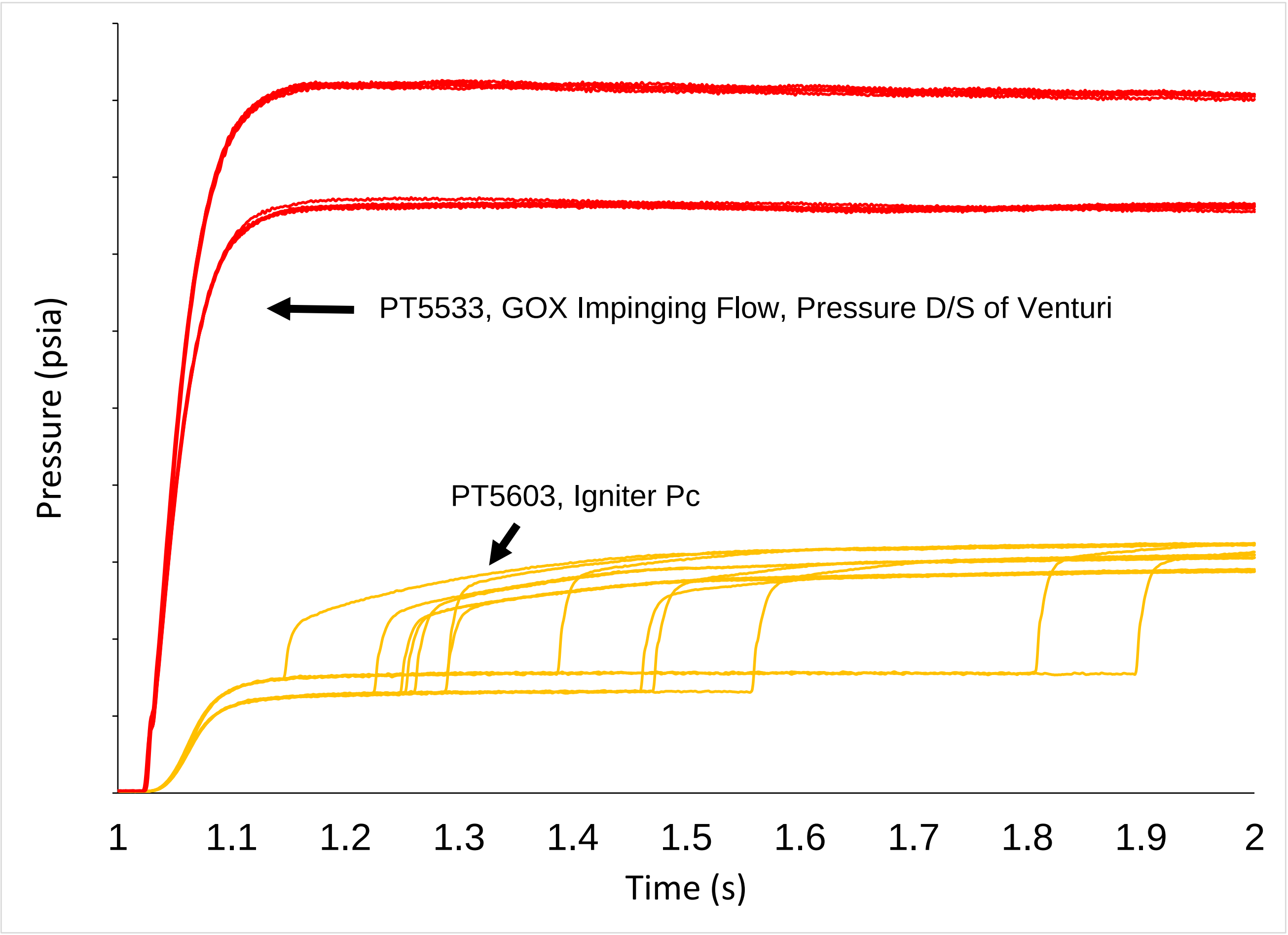
- Testing conducted over 5 test days; over 100 tests
- Primary objective was to demonstrate vacuum capability of exciter units
  - Secondary objective was to explore operational regime of ASI igniter as time permitted
- Timing of flows was initially set to mimic prior PCAD experience (LOX lead) at GRC



Results and Discussion

- Exciter-only checkouts (spark-only) showed both exciters operating down to 0.5 psia
  - Conventional-style exciter had a much stronger sparking capability than the compact unit, as was expected
- Test Day 1 (altitude hot-fire)
  - Both exciters tested (Compact first; Conventional second)
  - Compact exciter saw 1 of 5 ignitions; ignition delay ~500 ms
  - Conventional exciter saw 6 of 12 ignitions; ignition delays from ~140 to 550 ms
  - Propellants were remaining cold up to igniter venturi (possible liquids)
  - Testing focused on adjusting ox flowrate to maximize ignition potential
- Test Day 2 (altitude hot-fire)
  - Conventional exciter only
  - Adjusted operation of propellant conditioning to ensure gas propellants
  - 14 of 16 ignitions
  - Ignition delays from ~120 to 865 ms over range of conditions tested
  - Testing focused on adjusting flowrates/mixture ratio to maximize ignition potential

Results and Discussion – example of ignition delay variability

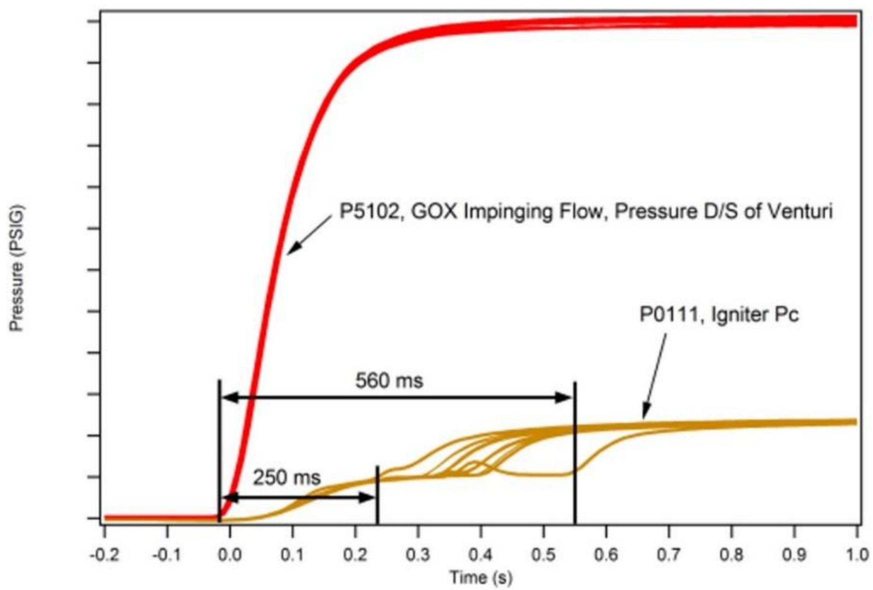


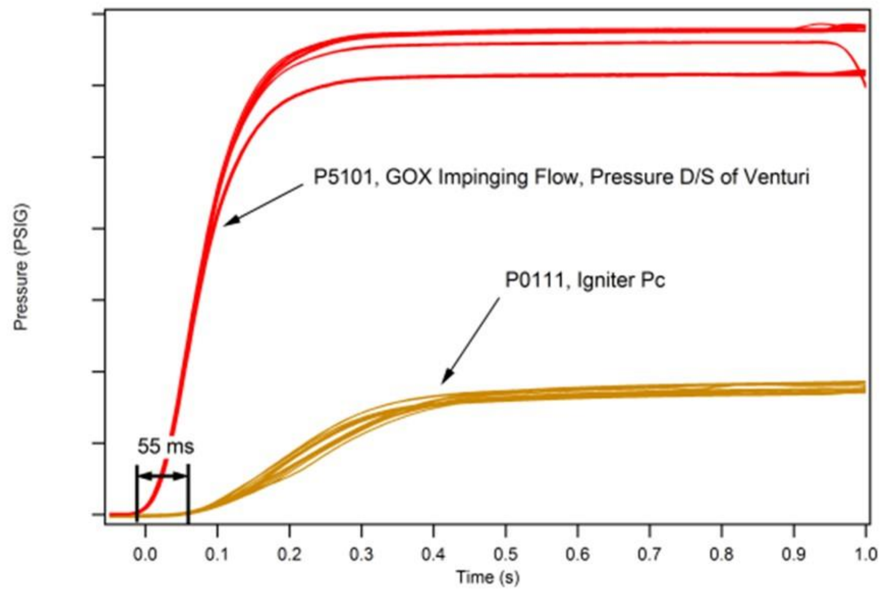
Ignition delays from ~120 to 865

Results and Discussion

- Test Day 3 (altitude hot-fire)
  - Compact exciter only
  - Similar conditions to Test Day 2
  - 2 of 17 ignitions
  - Ignition delays ~840 to 880 ms
- Test Day 4 (sea-level hot-fire)
  - Sea-level testing to compare against prior MSFC data
  - Both exciters tested
  - Compact Exciter: 3 of 11 ignitions;
    ignition delays ~400 to 770 ms
  - Conventional Exciter: 12 of 12 ignitions;
    ignition delays ~115 to 590 ms

Results and Discussion – MSFC test results



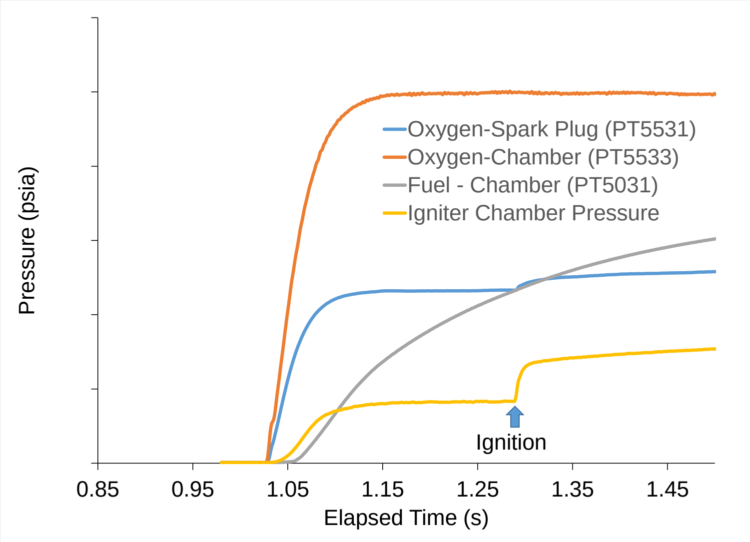


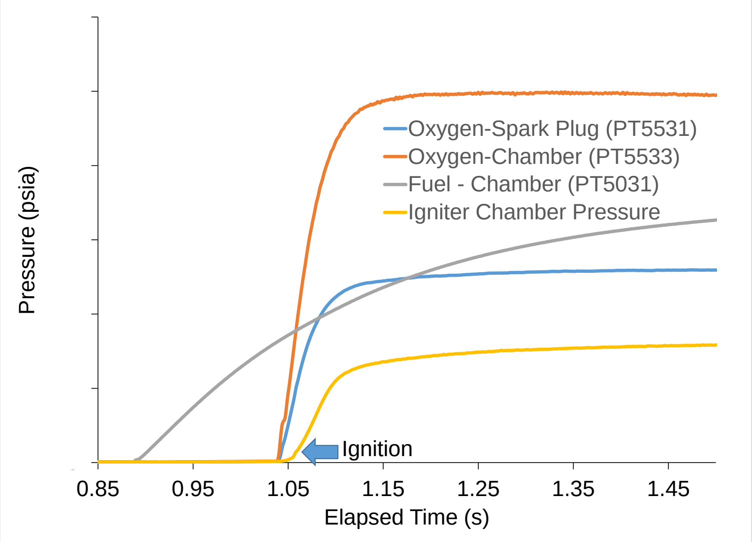
- MSFC experience with ASI showed some ignition delay variability in full engine Test Series 1, but more consistent ignition delays in engine Test Series 2
- Both tests had 150 ms fuel lead to LOX, operation at sea-level

Results and Discussion

- Test Day 5 (altitude hot-fire)
  - Conventional exciter only
  - Started at similar test conditions to Test Day 2 with 10 ms fuel lag
  - Objective was to gather as many tests as possible to gain statistical data on ignition delays
    - First 7 tests experienced 3 non-ignitions; ignition delays ~260 to 560 ms
    - No clear reason for non-ignition events
  - After reviewing MSFC data, adjusted timing to provide more fuel lead
    - Remaining 17 tests only adjusted fuel timing, providing more fuel lead; flowrates remained constant (17 of 17 ignitions)
    - 150 ms fuel lead demonstrated rapid ignitions (delays ~5 to 320 ms)

Results and Discussion

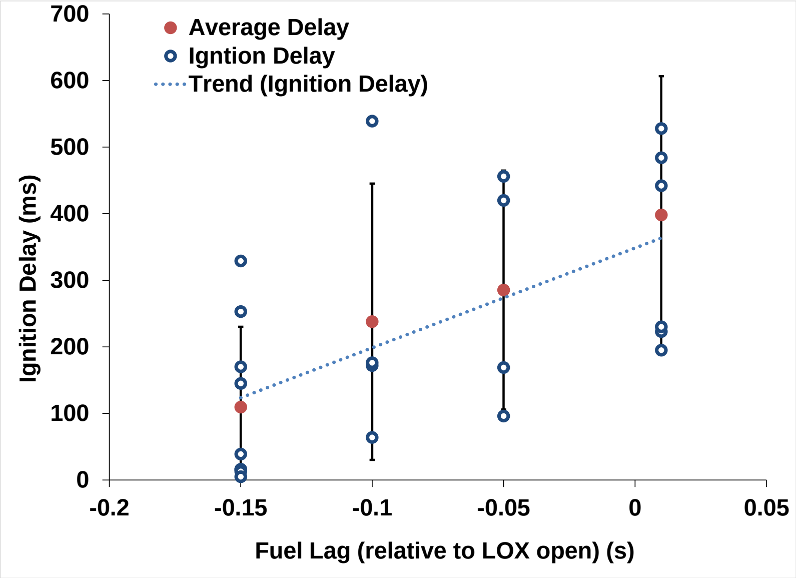




Typical ignition response with 10-ms ox lead

Typical ignition response with 150-ms fuel lead

Ignition delay vs. fuel lag timing



Conclusions

- An augmented spark impinging (ASI) igniter developed by NASA has been used frequently and successfully as a workhorse methane engine igniter – current test effort examined vacuum operation
- Two exciter units were tested, a compact exciter system which eliminated the high voltage ignition lead of conventional units, and a modified conventional exciter with improved sealing on the ignition lead.
  - Both exciters were tested at altitude conditions (~0.5 psia/25 Torr) and both exciters demonstrated vacuum ignition
- Testing showed that while the O/F of the core igniter flow has some influence on ignition potential, the transient condition during the manifold fill process was also critical to achieving a minimum and consistent ignition delay.
  - Providing a fuel lead for this hardware was necessary to ensure sufficient fuel delivery to manifold (lower transient O/F) and to minimize ignition delays
  - Testing with compact exciter supported previous PCAD conclusion that lower-energy sparks under right conditions could lead to ignition
  - Further testing of exciters utilizing more optimum fuel lead timing recommended for a better understanding of ignition delay behavior and ignition probability

Acknowledgements

- NASA Glenn Space Combustion and Materials Branch, in the Facilities, Test & Manufacturing Directorate, who helped to conduct this test series.
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- The late Herman Pickens of Orion Development. Herman passed away on May 16, 2016 at the age of 83. Herman was incredibly supportive of the internal R&D work at NASA MSFC for many years, up until his last months. His kindness, technical expertise, and enthusiasm for science and engineering will not be forgotten. His wife, Chris Pickens, also assisted in the development and production of compact exciter units used with great success in MSFC igniter and engine test programs.
- The NASA igniter tests were conducted as part of the Lander Technologies project, in the Advanced Exploration Systems program of the NASA Human Exploration and Operations Mission Directorate.